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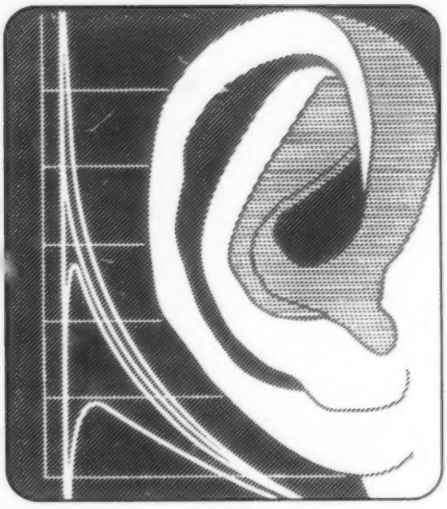

NOISE AND HEARING LOSS

P91-2E

by
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1. INTRODUCTION

Noise is undesirable sound, or sound that interferes with one's listening to what he or she desires to hear. Excessive exposure to loud noise (or sound) can cause damage to our ears. Sudden bursts or impulses of extremely loud noise such as gun shots or explosions, may result in an immediate, severe, and permanent hearing loss which is called acoustic trauma. Prolonged exposure to loud sounds may initially cause temporary hearing loss. Repeated exposures gradually cause permanent damage to the inner ear, resulting in loss of hearing ability. There is no medical cure for occupational hearing loss.

Hearing loss impairs a person's ability to perform work and interferes with social activity. It impairs the affected person's ability to understand spoken sounds, especially in group situations and in presence of other sounds.

It can make a person vulnerable to accidents; a worker with poor hearing ability may fail to hear warning signals. Impaired hearing jeopardizes safety both on and off the job.

Many studies link the level and duration of noise exposure with the degree of hearing loss. Results from such studies have helped develop standardized methods to estimate the extent of hearing loss in people exposed to noise.

This publication presents a review of the methods of calculating noise-induced hearing loss.

2. WHAT CAUSES HEARING LOSS

Common causes of hearing loss include:

- aging (presbycusis)
- noise exposure
- diseases of the ear
- consumption of certain medications.

This publication focuses on hearing loss due to noise exposure and on that due to aging. Hearing loss due to diseases of the ear or consumption of ototoxic medications is not described in this publication. The reader should consult medical literature for further study, or contact the Inquires Service of CCOHS.

Hearing Loss Due to Aging

Hearing sensitivity is most acute in young adults about 20 years of age. As people get older, their hearing deteriorates. Presbycusis is the medical term for age-related hearing loss. The degree of age-related hearing loss varies widely from one person to another. It is generally noticeable in people older than about fifty years of age.

Hearing Loss Due to Noise Exposure

Extremely loud sounds of short duration such as explosions or gun shots may produce immediate and severe hearing loss. This type of sudden damage to hearing is known as acoustic trauma. Most occupational noise exposures are unlikely to cause acoustic trauma.

Noise exposure of moderately high intensity can cause temporary hearing loss at the end of a workshift and permanent hearing loss after repeated prolonged exposure.

Temporary hearing loss or auditory fatigue is reversible. The time for complete recovery is variable; it may take several days. Most of the recovery occurs within a 16-hour rest period after an 8-hour workshift. For this reason this type of hearing loss is also known as temporary threshold shift (TTS).

Permanent hearing loss, (also known as permanent threshold shift or PTS) does not improve with time. On the contrary, it gradually increases as noise exposure continues day after day, month after month and year after year. Changes in hearing occur little by little and add up. These changes are not noticeable until the hearing loss is substantial and intereferes with everyday verbal communication. There is no medical cure for permanent hearing loss.

3. WHAT ARE THE MEASURES OF THE AMOUNT OF NOISE EXPOSURE?

The amount of noise exposure is expressed as a combination of the level of noise and the duration (months, years) of exposure. The unit of measuring the level of noise (sound) is the decibel, abbreviated as dB. Zero decibels is about the faintest sound of about 1000 kHz (kilohertz) frequency that a healthy young adult with normal ears can barely hear. Hertz (Hz) is unit of frequency; 1 Hz is equal to one cycle per second. The

workplace noise level is measured in A-weighted decibel units, abbreviated dB(A). The A-weighting approximately represents the relative sensitivity of the human ear to sounds of different frequencies. For more details please refer to the CCOHS publication, "Workplace Noise and Noise Measurement: A Basic Guide," P88-23E and the Canadian Standard CSA Z107.56 (see Further Reading List).

The A-weighted sound pressure level is generally referred to simply as noise level or sound level. The sound level of speech at typical conversational distance is between 65 to 70 dB(A). Sound levels above 85 dB(A) are potentially harmful if the exposure occurs daily for several years.

In the real world situation the noise level is not always steady; it may vary over a wide range of dB(A) levels. It may be intermittent as noisy machines go "on" and "off." It may occur as a series of impacts such as riveting or hammering, or a series of impulses due to the release of pressurized air or steam. In all the above situations a time weighted (TWA) average dB(A) level is used in estimating hearing loss. The averaging is done using a method known as equal energy principle (3 dB rule) and is often denoted by the symbol Leq. In this method, 93 dB(A) exposure for 4 hours is equivalent to 90 dB(A) exposure for 8 hours or 96 dB(A) exposure for 2 hours.

Another method of obtaining time-weighted average (TWA) is by using the 5 dB rule (OSHA method) which is not suitable for the calculation of hearing loss. However, if the level and temporal pattern of noise is known, one can estimate Leq from the 5 dB TWA (Fig. 1). For example, for steady noise, Leq is equal to TWA (5 dB). The difference is larger when noise exposure occurs as very short duration bursts of extremely loud noise.

When noise levels vary from one day to another, one can use average daily exposure as a measure of daily noise exposure. The International Standard ISO 1999 (1990) outlines the method for such calculations.

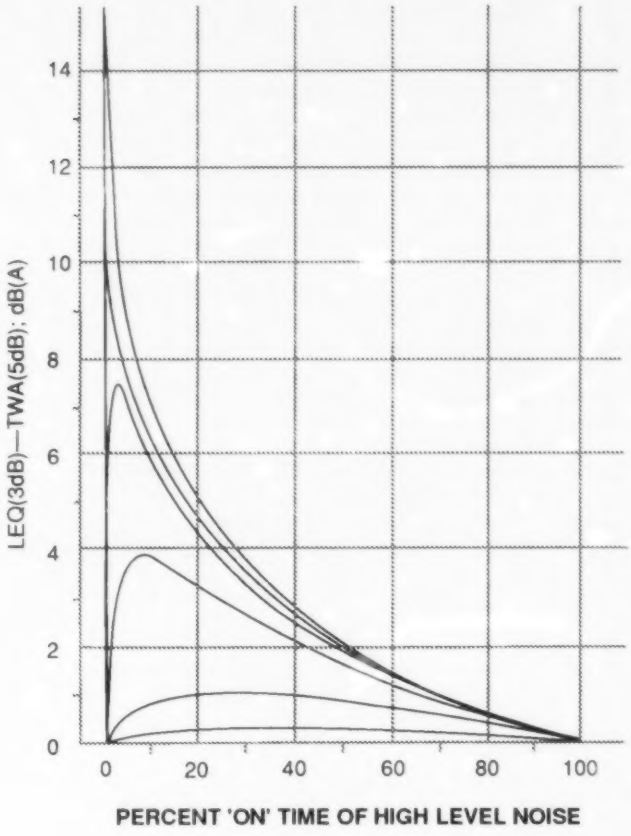

Figure 1 - Examples of the difference between average sound levels obtained by using the equal energy principle (3 dB exchange rate) and the 5 dB exchange rate. The numbers 10, 20, 30, 40, 50 on the graph indicate differences in dB(A) between the background noise level and an intermittent machine noise.

4. WHAT ARE THE MEASURES OF HEARING LOSS?

Testing of hearing ability (audiometry) involves determining the intensity of the faintest sounds that a person can barely hear. The decibel (dB) level of these barely audible sounds is called the hearing threshold level (HTL) and is determined for sounds with frequencies of 500, 1000, 2000, 4000 and 8000 Hz. Hertz (Hz) is the unit of measuring the frequency of sound. The information is presented as a table or chart, called an audiogram (Fig. 2).

Noise causes damage to the inner ear. In general, both ears are equally affected. In the early stages, the hearing threshold shift

is much greater at 4000 Hz compared to other frequencies (see fig. 2). This is sometimes referred to as the 4000 Hz notch, which is typical of noise-induced hearing loss. In advanced stages, the hearing loss progresses and spreads to other frequencies as well.

The hearing threshold level (HTL) is the magnitude of departure from a standard threshold. A commonly used standard is ANSI S3.6-1969 of the American National Standards Institute. In this standard 0 dB HTL represents the average hearing level of young adults (less than 25 years of age) who have no history of ear disease or hearing loss. A positive HTL (dB) represents poorer than average hearing. A negative HTL means the hearing is better than average.

Just by looking at an audiogram, one cannot tell whether or not noise is the cause of hearing loss in a given case. The knowledge of noise exposure history is essential to assess the cause-effect relationship.

within the range of human speech. In Canada, most regulatory agencies use the frequencies of 500, 1000, 2000 and 3000 Hz for determining the average HTL. Many jurisdictions consider an average HTL in excess of 25 dB (at 500, 1000, 2000 and 3000 Hz) as significant hearing loss.

5. HOW ARE NOISE EXPOSURE AND HEARING LOSS RELATED?

The association between prolonged noise exposure and premature hearing loss has been known for more than 100 years. Between 1950 and 1970 several studies of industrial workers enabled experts to develop mathematical equations for estimating hearing loss due to noise exposure. These studies also prompted the development of standardized methods for estimating hearing loss in noise-exposed workers. One such standard method is the International Standard ISO 1999 (1990).

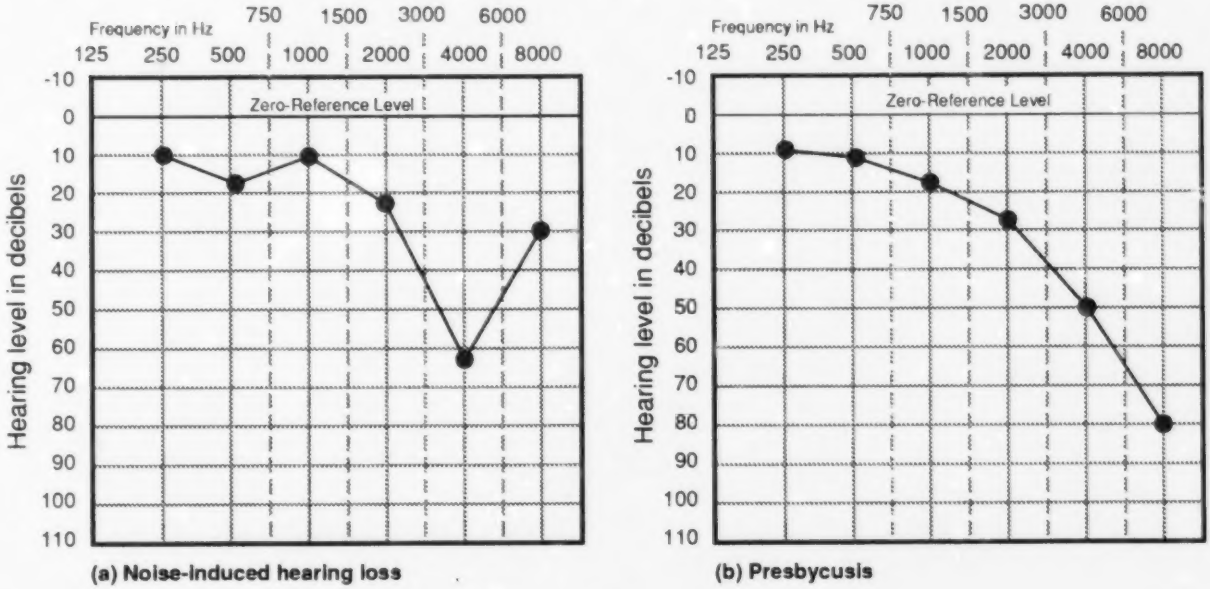

Figure 2 - Examples of audiograms of persons with:
(a) early stages of noise-induced hearing loss
(b) Presbycusis or age-related hearing loss.

Measuring Hearing Disability

Human speech sounds are mostly in the frequency range of about 500 Hz to 4000 Hz. Hearing disability is, therefore, determined by the average HTL at certain frequencies

Noise does not affect all exposed people equally. Some highly susceptible individuals suffer significant hearing loss after a brief exposure to moderately loud noise. Others may remain unaffected even after several years of exposure to loud noise. However, in a given workforce more and more people acquire hearing loss as the noise levels and exposure time increase.

Age-related hearing loss adds to noise-induced hearing loss. Like noise- induced hearing loss, the age-related hearing loss also varies widely from one individual to another.

Mathematical methods enable us to estimate the percentage of workers who will acquire a given degree of hearing loss. But, they do not enable us to determine what fraction of an individual's hearing loss is due to noise and what fraction is due to aging. Such judgements are generally based on the history of noise exposure.

For an individual worker, it is possible to estimate the percent risk of acquiring a given level of hearing loss. For example, if calculations show that 40 percent of workers in a group (all of whom are exposed to the same noise) are likely to acquire hearing disability, then we can say that any given worker in that group has a 40 percent chance of acquiring hearing disability.

6. HOW TO ESTIMATE NOISE-INDUCED HEARING LOSS

There are many different ways of estimating noise-induced hearing loss. All are based on actual studies of hearing levels in noise-exposed industrial workers. The results vary slightly from one method to another. In this section we present the ISO method and, briefly, another method developed in the United Kingdom by D.W. Robinson. Many other methods are reported in the scientific literature. The reader should consult the further reading list for a more detailed review.

Figures 3 to 7 show changes in hearing threshold levels with increasing sound levels and with increasing age. The graph (Fig 7, curve NN) marked "no noise exposure" represents hearing loss due to aging only. Other graphs show net hearing loss due to both noise exposure and aging. For simplicity, age correction is applied by assuming that everyone started noisy work at the age of 20 and the level of noise remained the same up to age 60. Although these simplified assumptions may not reflect the real world situation, they help understand how hearing loss depends on noise exposure and on aging.

ISO Method

The International Standard ISO 1999 entitled "Acoustics -Determination of Occupational Noise Exposure and Estimation of Noise-Induced Hearing Impairment" is widely used for estimating noise-induced hearing loss. This standard applies to average daily noise exposure levels of 75 to 100 dB(A).

In order to use the ISO standard one must know:

- equivalent continuous sound level (Leq) for a daily 8 hour work shift
- duration of exposure in months or years
- age and sex of the exposed person.

Table 1 shows calculated hearing threshold levels (HTL) of a group of persons all exposed to the same noise. Five percent of the worst affected people (percentile of 5) have HTLs equal to or worse than 15, 20, 40, 62, 68 and 67 dB at 500, 1000, 2000, 3000, 4000 and 6000 Hz, respectively. The hearing

Table 1 - **Hearing loss calculation by ISO method**
(Input Data: Age - 45 years / Sex - male / Exposure Duration - 20 years / Noise Level - 95 dB(A)

Percentile	Cause	Hearing loss (db) at audiometric frequencies in Hz					
		500	1000	2000	3000	4000	6000
5	Age & Noise	15	20	40	62	68	67
	Noise Alone	1	5	20	34	34	29
15	Age & Noise	11	15	31	49	56	53
	Noise Alone	1	4	16	29	30	24
25	Age & Noise	8	12	25	42	48	45
	Noise Alone	1	4	14	26	28	21
75	Age & Noise	-1	1	7	18	24	17
	Noise Alone	0	2	7	16	19	12
85	Age & Noise	-3	-1	3	13	18	10
	Noise Alone	0	2	5	14	17	10
95	Age & Noise	-7	-5	4	4	8	3
	Noise Alone	0	1	3	11	14	6

threshold levels of 85 percent of the exposed people (percentile of 85) are expected to be worse than -3, -1, 3, 13, 18 and 10 dB at 5000, 1000, 2000, 3000, 4000 and 6000 Hz respectively.

Figure 3 shows the median hearing loss in a group of noise-exposed persons. Fifty percent of the people are expected to acquire hearing loss worse than the median value and the other 50 percent are expected to be affected to a lesser extent.

Figure 4 shows the percentage of the exposed population with average hearing loss greater than 25 dB at frequencies of 500, 1000, 2000, 3000 Hz. More people are affected as the duration and/or level of noise exposure increases.

The age-related hearing loss represents the hearing levels of a "screened population" comprised of healthy people with disease-free ears.

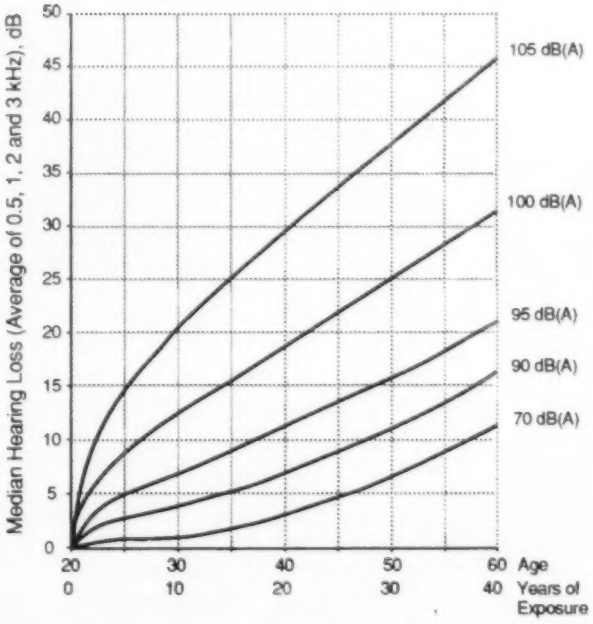

Figure 3 - Variation of median hearing loss (average of HTL at 500,1000,2000,3000 Hz) with age, noise level and duration of noise exposure using the ISO method.

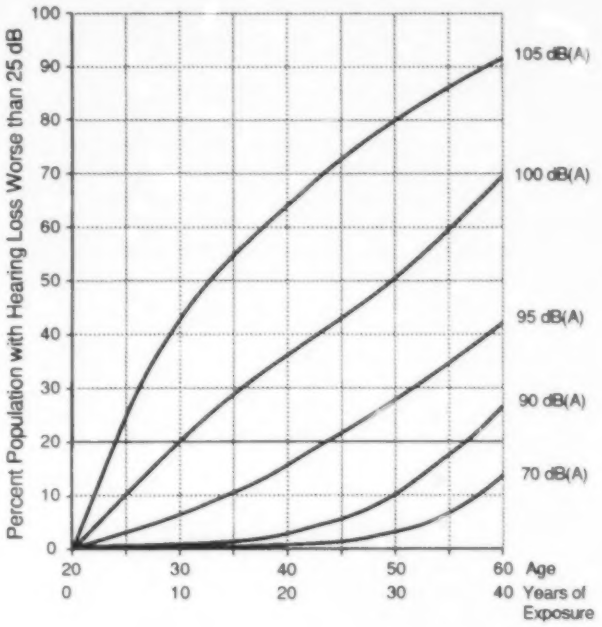

Figure 4 - Percent of noise-exposed population with hearing loss in excess of 25 dB for various noise levels and years of exposure as given by the ISO method. Hearing loss is defined as average threshold shift at 500, 1000, 2000 and 3000 Hz.

Robinson's Method

Robinson based his method of on a long-term study of hearing loss in industrial workers in the United Kingdom. The method is applicable under the following conditions:

- Daily noise exposure level is reasonably steady and does not exceed 120 dB(A).
- Noise exposure occurs for five days per week, for periods from one month to fifty years.
- Exposures of less than eight hours per day or fewer than five days per week but otherwise regular.

Figures 5 and 6 show the results obtained using Robinson's method with the same set of assumptions as for data in Figures 3 and 4, respectively. The 70 dB(A) curve represents the hearing loss entirely due to aging.

Comparison of results from the ISO and the Robinson's Methods

A comparison of Figure 3 with Figure 5 and Figure 4 with figure 6 reveals that both methods give comparable results.

The ISO method differs from Robinson's method in the way it accounts for hearing loss due to aging. In the ISO method, the age correction takes into account the variability within a population. In applying the age correction, it assumes that people who are highly susceptible to age-related hearing loss are also highly susceptible to noise-induced hearing loss. In the Robinson's method, the age correction does not vary from one individual to another.

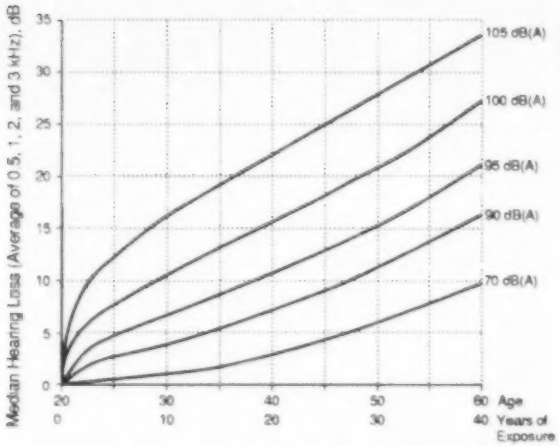

Figure 5 - Variation of median hearing loss (average of HTL at 500, 1000, 2000 and 3000 Hz) with age, noise levels and exposure duration using Robinson's method.

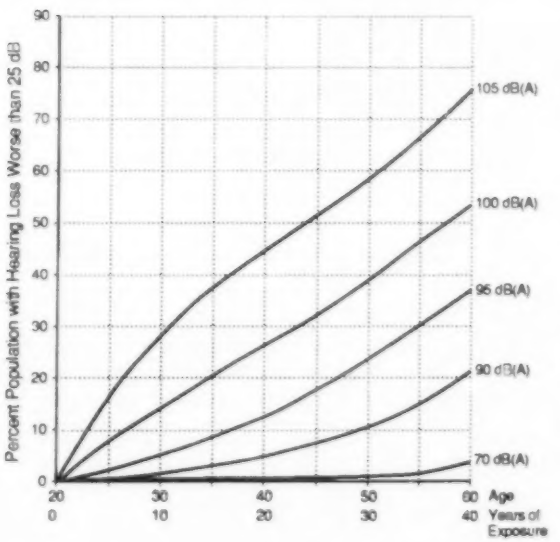

Figure 6 - Percent noise-exposed population with hearing loss in excess of 25 dB for various noise levels and years of exposure as given by the ISO method. Hearing loss is defined as average threshold shift at 500, 1000, 2000 and 3000 Hz.

Robinson's 1987 Report

In a 1987 report, Robinson analyzed data from several previous studies and reported an alternate method for calculating hearing threshold levels at 1000, 2000, and 3000 Hz, for noise exposure times up to 40 years and noise levels up to 100 dB(A).

Figure 7 shows the results of Robinson's 1987 study. Set (a) represents age-corrected hearing levels in noise-exposed people who have been medically screened to ensure that they possess normal and disease-free (otologically normal) ears. Set (b) represents age-corrected hearing levels in noise-exposed groups of typical populations.

The main reason for the difference between the two sets of results is due to higher prevalence of age-related hearing loss in the typical population compared to that in the otolgically normal group. The chance of finding people with hearing loss is higher in a typical population than in a screened otologically normal group. This effect is clearly noticeable in the difference between the NN (no noise) curves of the two sets.

7. HOW TO PREVENT OCCUPATIONAL HEARING LOSS

The surest way of preventing noise-induced hearing loss is to reduce the level of noise in the workplace. This can be done by designing quieter machines, using retrofits such as mufflers, enclosures, etc., on existing machines, and covering the walls and ceiling with sound absorbing materials.

Where it is not possible to apply any of the above engineering methods of reducing noise, these options are available: (1) reduction of the duration of exposure, and (2) use of ear protection. The protection afforded by ear protectors is highly dependent on the workers' ability to wear them properly at all times during noisy work.

The success of hearing conservation programs depends on employee participation, which can be greatly encouraged through education and training. The employee education should include such topics as the effect of noise on hearing; selection, use, fitting and care of hearing protectors; and early signs and symptoms of hearing impairment.

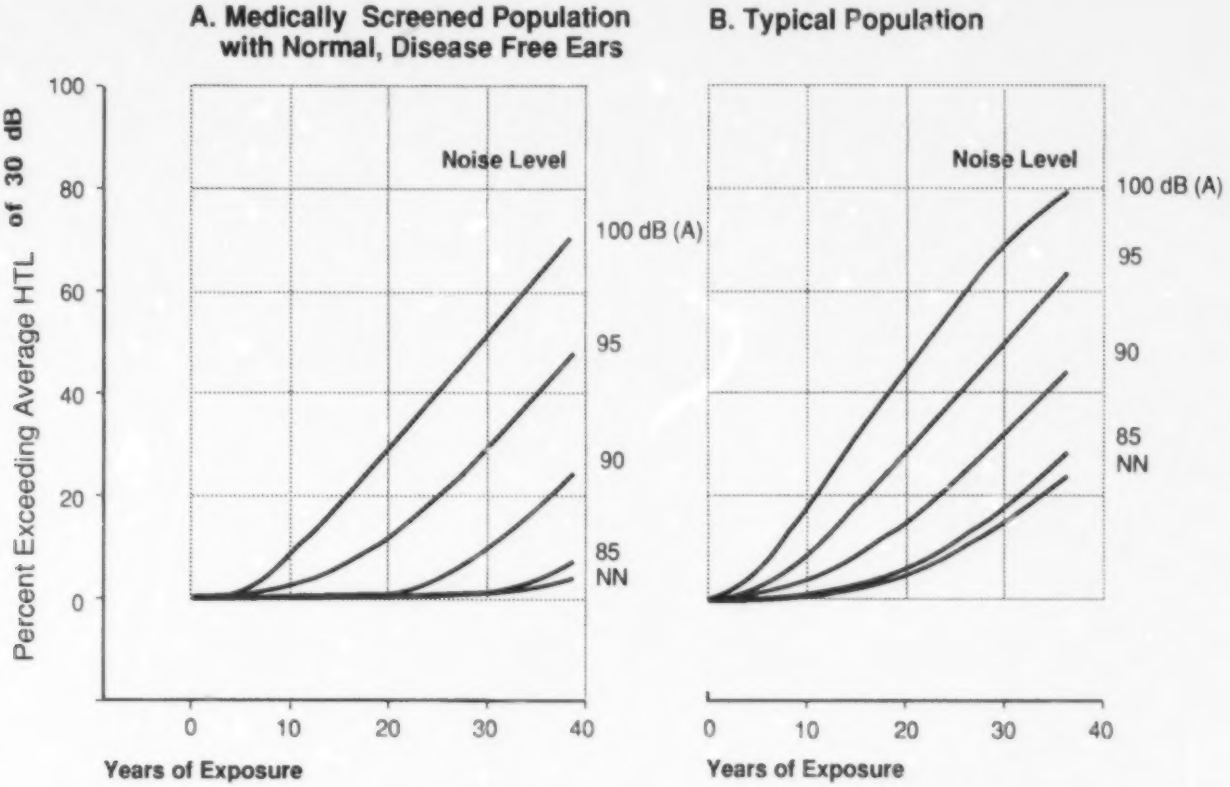

Figure 7 - Percentage of workers with an average hearing loss greater than 30 dB (averaged at 1000, 2,000 3000 Hz). The correction for age-related hearing loss was done by assuming that noise exposure started at age 18 years. Hearing threshold levels of non noise-exposed population (NN) are taken as:

(a) Hearing levels of people whose ears are medically screened to be normal and free from disease.
(b) Hearing levels of people in the typical general population.

8. SUMMARY AND CONCLUSION

The main objective of studying the relation between noise exposure and hearing loss is to determine safe limits for noise levels in the workplace. Many regulatory agencies allow 90 dB(A) noise levels for an eight-hour daily exposure. Such a limit will produce a measurable risk if the noise exposure continues for several years. Even 85 dB(A) daily exposure for 40 years results in some risk of hearing loss. There appears to be a reasonable agreement that sound levels below 75 dB(A) will not cause a permanent hearing loss even at the most sensitive frequency of 4000 Hz.

Noise-induced hearing loss progresses as long as noise exposure continues. When noise exposure stops, no further noise-induced hearing loss occurs. However, as a person gets older, the hearing loss due to aging constantly adds to the previously accumulated noise-induced hearing loss.

Changes in hearing occur rapidly in the early years of noisy work and then progress at a relatively slower rate as noise exposure continues. This effect is clearly noticeable for 95 dB(A), 100 dB(A), and 105 dB(A) noise levels (see Fig. 3). To prevent occupational hearing loss it is, therefore, essential that workplaces observe hearing conservation practices from the beginning of the noisy work.

We can summarize the relation of hearing loss to noise exposure as follows:

- Noise exposure can cause temporary hearing loss, permanent hearing loss, or a combination of temporary and permanent hearing losses.
- Permanent noise-induced hearing loss is caused by changes in the inner ear structures which cannot be replaced or repaired.

- The risk of permanent hearing loss depends on the level of noise and the duration of exposure.
- The amount of hearing loss produced by a given noise exposure varies from person to person. More people acquire hearing loss as the level of noise exposure and the duration of exposure increase.
- Most early noise-induced hearing losses pass unnoticed until they are severe enough to cause hearing disability.

Occupational hearing loss can be prevented by controlling noise exposure.

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NOTES